Influence of the visual attention span on child reading performance: A cross-sectional study

Marie-Line Bosse, Sylviane Valdois

Influence of the visual attention span on child reading performance: A cross-sectional study

Marie-Line Bosse and Sylviane Valdois

Laboratoire de Psychologie et Neuro-Cognition (UMR 5105 CNRS)

Université Pierre Mendès France

1251 Ave Centrale BP 47X 38040 Grenoble Cedex 9, France

Marie-line.Bosse@upmf-grenoble.fr

Sylviane.Valdois@upmf-grenoble.fr

Article paru dans *Journal of Research in Reading* (2009). Volume 32, 230-253

Abstract

The visual attention (VA) span deficit hypothesis was found to successfully account for variability in developmental dyslexia [Bosse, M.L., Tainturier, M.J. & Valdois, S. (2007), Developmental dyslexia: The visual attention span hypothesis. *Cognition*, 104, 198-230]. We conducted here a cross-sectional study on 417 typically developing children from first, third and fifth grades examining the role of VA span on the development of reading skills. A battery including reading, phoneme awareness and VA span tasks was administered. Results show that VA span predicts variations in learning to read independent of the influence of phoneme awareness. Moreover, whereas the specific influence of VA span on pseudo-word reading declines from first to third grade, VA span has a significant and sustained influence across grades for the irregular words. In addition to phoneme awareness, the VA span contributes to reading performance from the beginning of literacy instruction, suggesting that it might have a long-term influence on specific orthographic knowledge acquisition.

Keywords: visual attention span; reading acquisition; phoneme awareness; acquisition of orthographic knowledge; spelling-sound correspondences

Learning to read in an alphabetic system involves learning the relationships between sequences of visual symbols (i.e., relevant orthographic units such as graphemes, syllables, whole words) and the corresponding units of sounds (i.e., relevant phonological units such as phonemes, syllables or whole words). Most research on reading acquisition focuses on the role of phoneme awareness – sensitivity to the constituent sounds in words – for developing decoding skills (Castles & Coltheart, 2004; Goswami & Bryant, 1990; Hulme et al., 2002; Muter, Hulme, Snowling, & Taylor, 1998; Share, 1995). Beginning readers rely on phonological recoding to read unfamiliar words and nonsense words that have not received sufficient exposure to enter memory. Phonological recoding is further considered as part of a “self-teaching” device allowing the acquisition of word specific orthographic information (Ehri, 1991; Ehri, 2005; Ehri et al., 2001; Perfetti, 1992; Share, 1999, 2004). Evidence for a core phonological deficit in developmental dyslexia also supports a causal relationship between phoneme awareness abilities and learning to read (e.g., Snowling, 2000; Vellutino, Fletcher, Snowling, & Scanlon, 2004). Accordingly, theories of reading acquisition amply recognise the importance of phoneme awareness in the establishment of the reading system (e.g., Bradley & Bryant, 1983; Ehri, 1998; Harm & Seidenberg, 1999; Ziegler & Goswami, 2005).

In contrast, the potential impact of visual processes on reading acquisition is still under debate. The early visual components were typically considered as peripheral mechanisms beyond the scope of most reading models (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Harm & Seidenberg, 1999; see however Ans, Carbonnel, & Valdois, 1998). Furthermore, studies on reading acquisition disorders failed to show strong evidence for visual processing impairments in developmental dyslexia (Ramus et al., 2003; Shovman & Ahissar, 2006; Vellutino, 1979). Even those studies pointing to low level visual disorders (e.g., Lovegrove, Martin, & Slaghuis, 1986; Stein, 2003; Witton et al., 1998) or visual attentional impairments (e.g., Buchholz & Davies, 2005; Facoetti, 2004, for a review; Facoetti et al., 2003) in developmental dyslexia found that these visual processing disorders co-occurred with phonological impairments that were viewed as more likely to straightforwardly account for the poor reading performance of dyslexic individuals (Ramus et al., 2003).

It is nevertheless undisputable that reading requires visual processing and that differences in visual processing would affect the reading process, limiting what could be learned and the level of efficiency the system could achieve (Kwon, Legge, & Dubbels, 2007; Seidenberg, 1992). Currently, an increasing body of data suggest that dyslexic children show limitations in the number of string elements they can simultaneously process (Hawelka & Wimmer, 2005) and that differences in letter- or symbol-string processing might explain variability in reading performance (Pammer, Lavis, Cooper, Hansen, & Cornelissen, 2005; Pammer, Lavis, Hansen, & Cornelissen, 2004; Pelli, Burns, Farell, & Moore-Page, 2006).

The concept of VA span was introduced by our team (Bosse, Tainturier, & Valdois, 2007) to account for such difficulties in letter-string processing. This concept, applied to developmental dyslexia, showed that a VA span impairment contributed to the poor reading outcome of dyslexic children independently of their phoneme awareness skills (Bosse et al., 2007; Prado, Dubois, & Valdois, 2007; see also Valdois et al., 2003). The current paper will extend previous findings by examining whether VA span abilities independently contribute to reading acquisition in a large sample of typically developing children. We were particularly interested in the way the VA span contribution evolved with reading experience during the primary school years.

As the causal relationship between phonological processing and learning to read has been extensively reviewed elsewhere (e.g., Ehri, 2005; Vellutino, Fletcher, Snowling, & Scanlon, 2004), we will restrict our review to the limits of the phonological account of reading acquisition. We will then review evidence for the role of VA processes in reading acquisition and introduce the concept of VA span as grounded in the connectionist multitrace memory (MTM) model of polysyllabic word reading (Ans, Carbonnel, & Valdois, 1998).

Phonological processing and reading acquisition: the limits

It is now widely acknowledged that the relationship between phoneme awareness and reading acquisition is strong (e.g., Ehri, 2005, for a review) and bi-directional : phoneme awareness develops with literacy instruction and in turn the development of phoneme awareness improves reading acquisition. However, several studies have shown a decreasing role of phoneme awareness on reading performance, together with an increasing role of other factors -- such as rapid naming (de Jong & Van Der Leij, 2003; Kirby, Parrila, & Pfeiffer, 2003) or morphological awareness (Casalis & Louis-Alexandre, 2000; Deacon & Kirby, 2004; Sénéchal & Kearnan, 2007; Singson, Mahony, & Mann, 2000) -- with age and reading improvement. These results suggest that phonological skills well account for individual differences in early decoding, but that, in addition to phonological skills, the development of fluent reading through increased orthographic knowledge might involve some other kind of cognitive skills. In line with this view, it has been shown that controlling for decoding skills does not exclude variability in orthographic knowledge (Barker, Torgesen, & Wagner, 1992; Olson, Wise, Conners, & Rack, 1990) and that early orthographic knowledge predicts later orthographic knowledge even after controlling for early decoding skills (Cunningham, Perry, Stanovich, & Share, 2002; Sprenger-Charolles, Siegel, Béchennec, & Serniclaes, 2003). Some neuropsychological data also suggest that factors other than phonological skills could be involved in fluent reading acquisition. In particular, there have been reports of individuals with developmental dyslexia who failed to develop fluent reading skills and showed persistent difficulties with orthographic knowledge, despite good phoneme awareness (Castles & Coltheart, 1996; Dubois, Lafaye de Micheaux, Noël, & Valdois, 2007; Goulandris & Snowling, 1991; Hanley & Gard, 1995; Romani, Ward, & Olson, 1999; Valdois et al., 2003), while other individuals with developmental dyslexia developed fluent reading (and/or good spelling) despite poor phonological abilities (Howard & Best, 1996). It follows that acquisition of whole word knowledge, allowing fluent reading, seems to rely only partly on decoding skills and phoneme awareness and probably involves additional cognitive skills not yet fully understood.

Visual attention span and reading acquisition

Reading is obviously a visual perceptual task (Kennedy, Radach, Heller, & Pynte, 2000) that requires processing of multi-letter strings. Thirty years ago, Laberge and Samuels (1974) attributed a central role to visual attention in their model of visual information processing during word reading. They postulated that very beginning readers had to successively attend to each letter of the word they had to identify. With experience and training, letter identification becomes automatic and gradually, readers are able to attend to larger and larger units. According to their model, visual attention is involved in the definition of the orthographic units processed at a glance during reading (see also Laberge & Brown, 1989). To study visual processes underlying word recognition during a single glance in children, Aghababian and Nazir (2000) tested variation of reading performance as a function of fixation position within words. They found that, from the end of first grade, children exhibited a pattern of performance similar to that of expert readers (i.e., an optimal viewing position effect, see Nazir, 2000). However, children also demonstrated a word length effect not found in adults. This word-length effect suggests that young readers, despite being able to process short words with similar visual processes as older readers, are hampered when reading longer words. This might be because they could not extract enough visual information to process long words in a single fixation. Aghababian and Nazir (2000) found that poor readers further exhibited a deviant pattern of viewing position effect that could reflect a specific visual attention deficit associated with reading disability (see however, Dubois et al., 2007).

The involvement of attention in the visual processing of letter strings has been formalised by Bundesen (Bundesen, 1990, 1998; see also Bundesen, Habekost, & Kyllingsbaek, 2005, for a neurophysiological account of Bundesen's theory). He elaborated a theory of visual attention according to which the amount of information processed during a rapid multi-element presentation depends on the basic sensory effectiveness of each element (which reflects how well this element is processed when briefly presented in isolation) and on the attentional weight attributed to each element (which reflects the quality of the visual attention distributed on the array). Pelli et al. (2006) showed that very beginning readers who identify isolated letters as well as expert readers do, nevertheless exhibit low performance on tasks of multi-letter rapid processing. According to Bundesen’s theory, the poor performance of beginning readers in multi-letter processing would reflect a lower capacity than expert readers to distribute visual attention over the whole letter array, i.e., a smaller VA span according to Bosse et al. (2007). The VA span was defined as the number of distinct visual elements– i.e., the number of orthographic units in words, with respect to reading – that can be simultaneously processed at a glance.

The notion of VA span relates to the size of the visual attentional window as theoretically defined within the connectionist multi-trace memory model of polysyllabic word reading (Ans et al., 1998, hereafter MTM model). The MTM model provides a theoretical description of how VA processes operate in skilled reading. The model postulates that reading involves two types of reading procedures, a global and an analytic one. The two procedures differ in the kind of visual attentional and phonological processing they involve. An essential feature of the model is the inclusion of a visual attentional window through which information from the orthographic input is extracted. According to the theoretical model of reference, global processing typically requires a larger VA span than analytic processing. In global reading mode, the visual attentional window extends over the whole sequence of the word to be read. In analytic mode, it narrows down to focus attention on the different sub lexical orthographic units of the input string successively.

Although the MTM model has not yet been adapted to simulate reading acquisition, the model suggests that normal reading acquisition depends not only on the children's phoneme awareness but also on their VA span (Valdois, Bosse, & Tainturier, 2004). In line with most reading models (Coltheart et al., 2001; Harm & Seidenberg, 1999; Perry, Ziegler, & Zorzi, 2007; Ziegler & Goswami, 2005), the MTM model assumes that phonological skills are primarily involved in the acquisition of the analytic reading procedure. Reading in analytic mode would further contribute to the development of specific orthographic knowledge, an hypothesis in line with the self-teaching hypothesis proposed by Share (Bowey & Muller, 2005; Cunningham, 2006; Nation, Angell, & Castles, 2007; Share, 1999, 2004). The MTM model however makes the novel prediction that development of analytic processing skills should also depend on VA span abilities. Indeed, analytic processing requires the VA span to be large enough to process in parallel the whole letters constituting relevant sub lexical orthographic units. Moreover, since the acquisition of specific orthographic knowledge requires the whole letters of the input string to be simultaneously identified across all positions, a large VA span able to fit the length of input words is required for the establishment of the global reading procedure. The model therefore makes the prediction that development of both global and analytic processing skills should depend on VA span abilities, in addition to phonological processing skills.

The visual nature of the visual attention span

VA span abilities are typically assessed through two tasks of global and partial letter report. Even though they involve reporting verbal material, the global and partial report tasks cannot be considered as primarily phonological or verbal short-term memory tasks for a number of reasons. First, it has been shown that performance in the global report task is barely affected by a concurrent verbal short-term memory task (Pelli et al., 2006). Second, the patterns of errors produced in the global report task reflect visual rather than verbal confusions (Wolford, 1975). Third, because a single letter has to be reported in partial report, it is unlikely that verbal short term memory is a major factor. Dixon and Shedden (1993) showed that partial report is only minimally affected by articulatory suppression. Valdois & Lassus-Sangosse (submitted) reported very similar results with respect to global report, showing that the VA span disorder was not affected by a concurrent articulation task in dyslexic individuals. Previous studies from our team further showed that poor performance in global and partial report tasks primarily reflect a visual simultaneous processing disorder in the absence of letter naming speed or verbal short term memory problems (Lassus-Sangosse et al., 2008). Simultaneous processing here refers to the number of items processed during a fixation. Performance on the report tasks was further found to relate to eye movements in text reading while being unaffected by differences in phoneme awareness (Prado et al., 2007). Finally, VA span disorders were typically reported in dyslexic children who exhibited no phonological problems whereas a phonological impairment was not found to affect VA span abilities in developmental dyslexia (Bosse et al., 2007; Hawelka & Wimmer, 2005; Valdois et al., 2003). Thus, it can be assumed that the letter report tasks primarily reflect those visual attentional processes involved in the extraction of visual information from a brief visual display, thus the VA span.

The notion of VA span has further to be distinguished from the concept of perceptual span, which refers to the number of characters, in the visual field, from which useful information is obtained during a fixation. Indeed, although both the VA span and the perceptual span were estimated in number of letters and were found to increase with age (Rayner, 1986), these two concepts differ on several essential features. The perceptual span of beginning readers, estimated using a moving window technique (McConkie & Rayner, 1975), extends about 11 characters to the right of fixation (Rayner, 1986). In the present study, as in previous ones, the size of the VA span was found to vary from 2 to 4 letters. This important size difference reflects fundamental differences in both the theoretical conceptions and the methodological choices that supported these two concepts. Indeed, the perceptual span refers to the processing of letters in both the foveal and parafoveal area during text reading, a processing which influences eye movements and fixation times in text reading (Rayner, 1998). On the contrary, the VA span refers to the processing of characters presented in the foveal area only, a processing which does affect eye movements but specifically relates to the number of rightward fixations (thus, the length of rightward saccades) without affecting fixation durations during text reading (Prado et al., 2007). Further, the perceptual span does not suppose storage of information and its increase with age has been attributed to top-down cognitive factors such as linguistic processing, because this span is influenced by difficulty of the text (Rayner, 1986) and by word frequency (Rayner, Liversedge, White, & Vergilino-Perez, 2003). To the contrary, the VA span contributes to information storage in visual short-term memory, thus influencing single word reading and whole-word orthographic acquisition. Moreover, even if the VA span increases with age, this finding cannot be attributed to top-down linguistic processing as far as VA span abilities are estimated using unreadable strings of consonants. Actually, increase of the VA span with age more probably reflects improvement of the visual attentional processing system with reading experience, thus reflecting bottom-up visual and attentional factors. It follows that the VA span and the perceptual span are two distinct concepts.

Purpose of the current study

The MTM model's predictions on the role of the VA span in reading acquisition were first assessed in children with developmental dyslexia (Bosse et al., 2007; Prado et al., 2007; Valdois et al., 2003). Bosse et al. (2007) showed that the VA span was impaired in a good number of dyslexic children (59% of the French sample, 41% of the English sample) and that the VA span deficit dissociated from phonological problems in a subgroup of the participants (44% of the French sample and 34.5% of the English sample exhibited a single VA span deficit).

Moreover, results showed that VA span abilities independently contributed to reading performance in developmental dyslexia. However, these studies provided no information on how the VA span relates to reading performance during the normal acquisition process. In Bosse et al. (2007)'s paper, the relationship between VA span and reading acquisition was highlighted in two samples of French and British dyslexic readers who were 11 years old on average. These data might be compatible with a gradual improvement of VA span abilities with reading experience so that phonological skills would more strongly contribute to reading performance at the beginning of literacy instruction, at a time VA span abilities do not significantly affect reading performance. However, they are also consistent with a sustained influence of VA span across grades, so that the two hypotheses cannot be disentangled on the basis of our previous work.

In the current paper, we will study whether the VA span differently contributes to improvements in reading performance with grade, on a large sample of French children in first, third and fifth grade. Our purpose is threefold: We are first interested in assessing whether the VA span contributes to reading performance from the beginning of literacy instruction (1st grade) at a time the influence of phonological skills has been largely documented. Second, we will assess whether the influence of the VA span increases with reading experience or is rather sustained across grades. Lastly, we will investigate how specific is the VA span contribution. We are hypothesising that the VA span more specifically contributes to the acquisition of lexical knowledge (Valdois et al., 2004); In line with this hypothesis, the VA span influence on reading performance should be stronger or more stable during the acquisition process for the irregular words as compared to pseudo-words.

METHOD

Participants

Participants were 417 children from various social backgrounds who were recruited in eight primary schools within the urban area of Grenoble. For each grade, children were sampled from four different classes belonging to different schools so that the probability of teacher or teaching method effects was greatly reduced. This sample consisted of 85 girls and 72 boys in first grade, 59 girls and 67 boys in third grade and 68 girls and 66 boys in fifth grade (see mean chronological age in Table 1). All children were native French speakers with normal or corrected to normal vision. Their non verbal IQ percentile (Raven, Court, & Raven, 1998) was 50.8 on average. IQ was equivalent across grades (see Table 1; all ranges = 10-95, F (2,414) = 2.78, ns).

Thirteen percent of the third grade participants and nineteen percent of the fifth grade participants had repeated a grade. We chose not to remove them from the experimental population because our main goal was not to investigate the cognitive skills of children at a given age (or school level) but to study the impact of various cognitive skills on reading performance. However, age was systematically controlled in the analyses. The mean reading age (Table 1) estimated with the “Alouette” Reading Test (Lefavrais, 1965) was slightly different from chronological age ($t(156) = -3.9$, $p < .001$ in first grade; $t(125) = 2.7$, $p < .01$ in third grade; $t(133) = 4$, $p < .001$ in fifth grade).

Table 1 about here

Tests and material

Children were tested on various reading, phoneme awareness and visual attention span tasks. IQ and short term memory were further evaluated as control variables since the former is known to relate to reading (e.g., Gayan & Olson, 2003) and the latter to phoneme awareness (Alloway, Gathercole, Willis, & Adams, 2004). A task of letter identification threshold was further given to the participants in order to control processing rate of single letters.

The reading tasks

Single word reading

The participants were asked to read aloud three lists (extracted from the "ODEDYS Test", Jacquier-Roux, Valdois, & Zorman, 2002) of 20 high frequency (HF) regular words, 20 HF irregular words matched on length with the regular words, and 20 pseudo-words matched on length, phonemic and orthographic structure with the regular words. Because the third and fifth grade participants might be more prone to show ceiling accuracy performance on HF items, they were further submitted to three additional lists of 20 low frequency (LF) regular words, 20 LF irregular words and 20 matched pseudo-words. Regular and irregular word frequency was 126 and 120 per million respectively for the HF lists, 18 and 12 per million for the LF lists (from MANULEX, a database from French elementary school-readers, Lété, Sprenger-Charolles, & Colé, 2004). Each list was printed on a white sheet of A4 paper, in a lower-case format (Times, 14 pt), with all items in columns on the same sheet. The participants were asked to read the items aloud as quickly and accurately as possible. They were informed of the nature of the items (i.e., real words or pseudo-words) before beginning to read. For each list, the number of items correctly read (hereafter reading score) and time taken to complete each list (reading rate) were recorded directly as the test was completed. Performance on the two lists of HF and LF words were collapsed to obtain an average reading score for the regular and the irregular words in third and fifth grades. An average pseudo-word reading score was also computed from the two lists of pseudo-words.

The phoneme awareness tasks

All the participants were given three tasks of phoneme awareness. However, considering that phoneme awareness is acquired more easily in relatively transparent languages, such as French (Share, 2008), a fourth and more difficult task was further designed for the third and fifth grade children only. For each task, the participants were given a set of practice items for which they received feedback. No feedback was provided on the experimental items. The experimenter said aloud each item twice and handwrote participant's responses. Children were asked to attempt all items. The dependent variable was the percentage of correct responses.

Phoneme segmentation

A set of 15 words (see Appendix) was presented auditorily to the participants who had to successively pronounce each word's constitutive phonemes (e.g., /kado/ "cadeau" gift → /k–a–d–o/). The words were made up of 4 phonemes on average (range 3-5), 7 words ended with a closed syllable (e.g., CVC, /fuR/ "four" oven; CVCC, /poRt/ "porte" door), the other 8 words ended with CV syllables (e.g., /kado/ "cadeau" gift; /kRapo/ "crapaud" toad).

Acronyms

Two words were successively pronounced by the experimenter (one word per second). The children were required to extract the first phonemes of each word and combine them to produce a syllable. For example, the child heard /foto/ - /aRtistik/ ("photo" photo, "artistique" artistic) and had to say /fa/. The test comprised 10 series of 2 words (see Appendix) made up of 4.4 phonemes on average (range 2 - 8). Seven words began with a vocalic phoneme corresponding to a digraph so that an erroneous word was generated if the first letter was extracted instead of the first phoneme (the response in the example would be /pa/ if orthographically biased in the previous example). The task was taken from the BELEC battery (Mousty, Leybaert, Alegria, Content, & Morais, 1994).

Phoneme deletion

The participants had to delete the first sound of a word and produce the resulting pseudo-word (e.g., /uti/ "outil" tool → /ti/; /drapo/ "drapeau" flag → /rapo/). Twenty experimental words were presented to third and fifth graders (see Appendix), a shorter list of 15 words to first grade children. In the 20 word list, seven words began with a vocalic phoneme corresponding to a multiple letter grapheme so that deletion of the first letter (instead of the first phoneme) yielded incorrect responses; nine words began with a consonantal cluster, four with a singleton (2, 9 and 4 respectively for each type of phoneme in the 15-word list).

Spoonerisms (third and fifth graders only)

The task required exchanging the first phonemes of two heard words (e.g., /banan/ - /fisèl/ ("banane" banana – "ficelle" string) → /fanan/ - /bisèl/). Responses were always two pseudo-words. The test comprised 10 series of 2 words (see Appendix) made up of 4.8 phonemes on average (range 4 - 6). All the words began with a singleton.

The visual attention span tasks

The participants were submitted to two tasks of whole and partial letter-string report designed to study processing of letter information perceived during a single fixation. The same tasks have been successfully used in our previous research (Bosse et al., 2007; Prado et al., 2007; Valdois et al., 2003) to highlight a visual attention span disorder in developmental dyslexia and have been found to specifically tap those visual processes involved in the simultaneous processing of letter-strings (Lassus-Sangosse, N'Guyen-Morel, & Valdois, 2008; Prado et al., 2007; Valdois & Lassus-Sangosse, submitted). The tasks were displayed on a PC computer using E-prime software (E-prime Psychology Software Tools Inc., Pittsburgh, USA).

Global report

Stimuli were 20 random 5-letter strings (e.g., R H S D M) built up from 10 consonants (B, P, T, F, L, M, D, S, R, H). Each letter appeared a total of 10 times, twice in each position. The letters were presented in upper-case (Arial, 7 millimetres high) in black on a white background. The strings contained no repeated letters. Two subsequent letters never corresponded to a French grapheme (e.g., PH, TH) or a frequent bigram in French (e.g., TR, PL, BR). The 5-consonant strings never matched the skeleton of a real word (e.g., FLMBR for FLAMBER “burn”). The distance between each letter centre was 1 cm. The array subtended an angle of approximately 5.4°.

At the start of each trial, a central fixation point was presented for 1000ms followed by a blank screen for 50 ms. A 5-letter sequence was then presented horizontally centred on the fixation point for 200ms. The participants’ task was to name as many letters as possible immediately after they disappeared, without position constraint. The child’s response was recorded and the experimenter pressed a button to initiate the next trial. There were ten practice trials for which participants received feedback. No feedback was given during the 20 test trials. Performance was scored two ways: we calculated both the percentage of 5-letter strings entirely reported (in terms of identity not locations; hereafter "String-score") and the percentage of letters accurately reported across the 20 trials whatever their position in the string (hereafter "Letter-score").

Partial report

Fifty 5-letter sequences (e.g., T H R F D) were built up from the 10 consonants used in the global report condition. Each letter appeared 25 times, five times in each position. Strings contained no repeated letters. Letters were presented with the same size and spacing as in the previous task. The probe indicating the target letter to be reported was a vertical bar (5 millimetres high) presented for 50 ms, 1 cm below the location where the target letter had previously appeared. Each letter was used as target once in each position.

At the start of each trial, a central fixation point was presented for 1000 ms followed by a blank screen for 50 ms. A 5-letter string was then presented at the centre of the display monitor for 200 ms. At the offset of the letter string, the cue appeared for 50 ms. Participants were asked to report the cued letter only. They were instructed to be as accurate as possible and no time pressure was applied. After their oral response, the experimenter pressed a button to start the next trial. The task began with ten practice trials. No feedback was given during the 50 test trials. The score was the percentage of accurately reported target letters.

The Control tasks

Letter identification

Performance on letter report tasks is known to be influenced by the processing rate of single letters (Duncan et al., 2003; Laberge & Samuels, 1974). To control for this latter skill, each of the 10 letters used in the report tasks were randomly presented (5 times each) in the centre of the screen, at 5 different presentation durations (33 ms, 50 ms, 67 ms, 84 ms and 101 ms). The letters had the same physical characteristics as in the letter-report tasks. Each of the fifty trials began with a central fixation point which was presented for 1000 ms, followed by a letter. At the offset of the letter, a mask (13 mm high, 37 mm wide) was displayed for 150 ms. The test trials were preceded by 10 practice trials (2 for each presentation time) using other letters and for which participants received feedback. Participants were asked to name each letter immediately after its presentation. For each presentation duration, the number of letters accurately identified was weighted, so that the shortest presentation duration had the highest weight (the weighting was 5 for 33ms, 4 for 50ms, 3 for 67ms, 2 for 84ms, 1 for 101ms). The total score was the sum of all weighed scores.

Verbal Short term memory

Because it requires the oral report of five letter names, performance in global report might be affected by differences in verbal short term memory. To control for this potential impact, the participants were administered a forward and backward digit span test designed by the researchers. Digits from 1 to 10 were randomly chosen to build up sequences from 2 to 9 digits. Each test began with a two digit trial. When the participant repeated the digit string accurately (identity and order), the next trial was one digit longer. When s/he failed, another trial of the same length was attempted. For each test, the span was the maximum number of digits accurately repeated once. A memory score was calculated as the sum of the two forward and backward spans.

Non verbal IQ

The Raven Progressive Matrices (Raven et al., 1998) were used to estimate the participants' level of non verbal intellectual ability.

General Procedure

The participants were tested individually during a one hour session by trained experimenters in a quiet room at school. The reading, phoneme awareness, visual attention span and control tasks (except Raven matrices administered during a collective session) were mixed and presented in a fixed order to all the participants. Short breaks were scheduled between the tasks.

Design and Analyses

Most analyses were conducted separately for first, third and fifth grades. A correlation analysis was first conducted on the measures of reading, phoneme awareness, VA span and control tasks. Second, to reduce the data set before exploring the concurrent predictors of reading skills, we conducted a principal components analysis with varimax rotation on the data from the phoneme awareness tasks and the VA span tasks. All factor loadings greater than +/- 0.70 were used for interpretation. Then, the factor scores derived on the basis of the principal components analysis were used to explore the concurrent predictors of reading sub skills. In addition, regression analyses were done for each grade separately. Lastly, an omnibus analysis including Grade as a variable was conducted to assess whether differences in the contribution of the two variables of interest (phoneme awareness vs. Visual attention span) to reading performance significantly varied across grades.

Results

Overview of the Participants' Performance

Table 2 shows the mean performances for the reading, phonological and VA span variables, separately for each grade. As the times taken to complete each list were highly correlated at all grades (all $r > .85$), a single reading rate variable was computed as the mean time (in seconds) to read a word (Table 2). Analyses of variance revealed a main grade effect on all the variables (see F and MSe values in Table 2). Planned comparisons showed that first graders' reading performance differed significantly from that of the older children, whatever the item to be read ($F(1, 414) = 153.2$ for RW, $F(1, 414) = 373.5$ for IW, $F(1, 414) = 197.2$ for PW, $F(1,411) = 89.6$ for reading rate, all $ps < .001$). Performance also improved on all the reading tasks between the third and fifth grades ($F(1, 414) = 10.5$ for RW, $F(1, 414) = 52.1$ for IW, $F(1, 414) = 11.3$ for PW, $F(1,411) = 16.5$ for reading rate, all $ps < .001$). Phoneme awareness and VA span also improved with grades (see Table 2). Planned comparisons showed that first graders' performance in the phonological tasks differed significantly from that of older children ($F(1,414) = 113.7$ for deletion task, $p < .001$; $F(1,414) = 22$ for acronym task, $p < .001$; $F(1,414) = 5.1$ for segmentation task, $p < .05$) and kept on increasing from Grade 3 to Grade 5 ($F(1,414) = 6.2$ for deletion task, $p < .05$; $F(1,414) = 6.6$ for acronym task, $p < .05$; $F(1,414) = 7.3$ for segmentation task, $p < .01$). In global report, most first grade children failed to report any of the five-letter sequences entirely (String-score: mean = 7.3%, median = 0%) although they were able to report 57% of the letters on average (median letter-score = 56%; corresponding to 2.8 letters accurately reported on average). Planned comparisons showed that first graders' performance in global report differed significantly from that of older children ($F(1,414) = 225.2$ for string-score; $F(1,414) = 374.5$ for letter-score, all $ps < .001$; 3.9 letters were accurately reported on average in third grade) and kept on increasing between the third and fifth grades ($F(1,414) = 23.9$ for string-score; $F(1,414) =15$ for letter-score, both $ps < .001$; 4.2 letters were accurately reported on average in fifth grade). In partial report, first grade children reported accurately 66% of the targets (corresponding to 3.3 letters per item on average) and third grade participants were more than 80% accurate (i.e., 4.1 letters out of 5 were accurately reported). Planned comparisons showed that first graders' performance in partial report differed significantly from that of older children ($F(1,411) = 174.9$, $p < .001$) and kept on increasing between the third and fifth grades (i.e., 4.4 letters out of 5 accurately reported; $F(1,411) = 10.2$, $p < .01$).

Table 2 about here

Correlation Analyses

In Table 3, values above the diagonal show correlations between the variables after controlling for age. Raven matrices score, letter identification and short term memory were further controlled in partial correlations (Table 3, below the diagonal) and in regression analyses because scores on these tasks correlated significantly, with some of the reading scores.

Strong correlations were found between the measures thought to reflect the same cognitive processes. However, only some correlations between the phonological and the letter report tasks were found significant in the partial correlations (Table 3, below the diagonal), suggesting that these tasks mainly involved different cognitive processes. As expected, phonological and reading skills were correlated. However and more importantly for the current purpose, strong correlations were found between the letter report tasks and reading performance. The same general pattern was obtained when correlations were computed separately for each grade.

Table 3 about here

Factor analyses

The correlation analysis suggests that phoneme awareness tasks and VA span tasks might measure different cognitive skills. To evaluate the independence between a general phonological ability -- as assessed through the phoneme awareness tasks-- and the VA span --as estimated through the two letter report tasks--, a factorial analysis was conducted on these two types of tasks, separately for each grade. If independence were confirmed, the analysis would allow further simplification of the data in providing a composite phonological factor and a composite VA span factor. Scores on the phonological tasks (3 in first grade, 4 in later grades) were entered in the factorial analyses together with the scores on the two letter report tasks. In order to avoid giving too much weight to the global report task, only one of the two global measures was entered in the analyses.[1] String score was not used in first grade because of the floor effect (57% of the children had a zero score). Letter score was not used in later grades because it showed less variance than string score.

Table 4 about here

Results of the principal components analyses after a varimax rotation are presented in Table 4. Each analysis extracted two orthogonal factors. The first set of factors (Eigen values = 2.02, 2.10 and 2.21) accounted for 40, 35 and 37 percent of the variance respectively for Grade one, three and five. All received high loadings from the phonological tasks. The second set of factors (Eigen values = 1.68, 1.66 and 1.70) accounted for 34, 28 and 28 percent of the variance in each grade respectively. All received high loadings from the letter report tasks.

In the subsequent analyses, we used the factor scores derived from the principal components analysis as a phonological factor (factor 1) and as a VA span factor (factor 2). [2]

Table 5 provides, for each grade, results of the correlations between the two factors extracted from the factorial analysis and the other measures. Results show that the two factors are significantly related to reading performance. In 1st and 3rd grades, both the phonological and VA span factors were significantly correlated with all of the reading measures. In Grade 5, the phonological factor correlated only with the regular word and pseudo-word reading scores, whereas the VA span factor was correlated with all the reading measures. At all Grades, a significant negative correlation was found between reading rate and VA span. The phonological factor also correlated negatively with reading rate, except in 5th grade.

[1] When the two measures of string score and letter score were entered in the equation, the only important change in the analyses was that the VA span factor was extracted first instead of the phonological factor.

Non verbal IQ more strongly correlates with the phonological factor than with the VA span factor, while the reverse is found for each factor and letter identification. Short term memory also correlates with both the phonological and VA span factors. Taken as a whole, the present results attest that both phoneme awareness and VA span correlate with reading performance. However, correlations were also found between these two skills and the control variables. Consequently, hierarchical regression analyses were conducted with the aim of separating the unique contribution of each phonological and VA cognitive process to reading performance.

Table 5 about here

Multiple regression analyses

A series of multiple regression analyses was conducted to assess whether phoneme awareness and VA span accounted for independent variance in reading for each grade. In a first step, four control variables–chronological age, Raven score, verbal short term memory and letter identification threshold– were entered in the equation. In the second and third steps, phonological and VA span factors were successively entered in the regression. Two different sets of regressions were carried out: one forcing the entry of the phonological factor as the second step and the other forcing the entry of the VA factor in step 2. The increase in variance associated with the last variable entered in the regression analyses is presented in Table 6. It represents the unique contribution of that variable to reading performance.

Table 6 about here

Whatever the grade, control variables accounted for sizeable amounts of variance in the reading measures (from 13.6% to 19.6%; except for reading rate in fifth grade, 5.7%, ns). The total amount of variance in reading performance explained by the combined control variables, phonological and VA span factors was substantial. As

[2] As Factor 1 also captured some information from global report task and Factor 2 captured some information from spoonerism or deletion tasks, additional analyses were conducted with a pure phonological and VA span factor represented by the mean performance

shown in Table 6, the total model R^2 values ranged from 27.5 % for regular word reading in Grade 3 to 50.4% for regular word reading in Grade one. In first grade, the unique contribution of both the phonological and VA span factors to reading performance was highly significant for all the measures. In third grade, both the phonological and VA span factors also made unique contribution to the children's reading outcomes. The phonological factor still made small but significant contributions to reading accuracy (from 2.3 to 6.8% of explained variance) in fifth grade but not to reading rate. The unique contribution of the VA span factor to both reading accuracy and reading rate remained highly significant in fifth grade.

Comparisons between grades were made using regression analyses including the control variables, the phonological and VA factors, two orthogonal contrasts for grades (first contrast : Grade 1 = 2, Grade 3 = -1; Grade 5 = -1; second contrast: Grade 1 = 0; Grade 3 = 1; Grade 5 = -1) and the interactions between these contrasts and all the other factors. These analyses revealed that the independent contribution of the phonological factor to reading was far larger in first grade than in later grades ($B = 4.2$, 3.1, 3.3 and -.4, $t(392) = 8.3$, 5.5, 5.7 and -6.5 respectively for RW, IW, PW and reading rate, all $ps < .001$) and was similar in Grade 3 and Grade 5 ($B = .7$, 1.6, .4 and -.1, $t(392) = .7$, 1.6, .4 and -.1, all NS). The unique contribution of the VA span factor to reading was larger in first grade than in later grades for reading accuracy of regular words and pseudo-words (respectively, $B = 2.8$ and 2.1, $t(392) = 5.5$ and 3.5, $ps < .01$) and for reading rate ($B = -.4$, $t(392) = -6.8$, $p < .001$). In contrast, contribution of the VA span remained stable over grades for the irregular words ($B = 1.0$, $t(392) =1.7$, NS). Lastly, the unique contribution of the VA span factor was equivalent in third and fifth grades for all the reading measures ($B = .8$, 1.1, .7 and -.1, $t(392) = .8$, 1.1, .7 and -.6, respectively for RW, IW, PW and reading rate, all NS).

In sum, the present results suggest that the VA span contributes to reading performance independently of phonological skills, at all grades tested. The results further suggest that the contribution of phonological skills decreases after the first grade for all the reading measures. Essentially the same pattern characterises the evolution

on the phoneme awareness tasks and on the letter report tasks. Results were very similar to those reported here.

of the VA span contribution to reading performance across grades, except for irregular words. For these later items indeed, contribution of VA skills remains stable across grades.

Discussion

This article investigated specific contribution of the VA span to the improvement of reading performance during the primary school years. For this purpose, an extensive battery of reading, VA span and phoneme awareness tasks, was administered to a large sample of children in 1^{st}, 3^{rd} and 5^{th} grades. Hierarchical regressions were conducted to determine to what extent phoneme awareness and VA span contributed to reading acquisition independently. Other variables — such as age, non verbal IQ, verbal short term memory and letter identification — likely to influence reading acquisition were partialled out in order to isolate the unique contribution of each predictor to reading performance.

Impact of the VA span on reading acquisition

In first grade, the VA span was found to correlate with all the measures -- reading accuracy and reading rate -- of reading performance whatever the type of items to be read (real words or pseudo-words). Results further showed that reading level measured at Grade 1 is affected by VA span abilities, after the effects of phoneme awareness, age, IQ and verbal short term memory have been taken into account. These findings suggest that VA span abilities significantly and independently contribute to reading performance from the beginning of literacy instruction. In line with the huge amount of data showing that phoneme awareness is crucial for literacy development, (e.g., Bowey, 2005; Castles & Coltheart, 2004; de Jong & van der Leij, 1999; Ziegler & Goswami, 2005), the present findings further confirm the link between phoneme awareness and early reading acquisition. They however extend previous findings in showing the independent and significant contribution of phonological skills to variance in reading age at Grade 1, after control for the effect of the VA span. Both phoneme awareness and VA span skills thus appear as significant contributors to reading performance from the beginning of literacy instruction.

Cross-grade analyses showed that both the phoneme awareness and VA span scores increase with reading development. The two factors were further found to independently contribute to reading performance throughout the primary school years. However, results also revealed a tendency for their contribution to reading performance to be stronger in first grade than in later grades. Indeed, in accordance with previous reports (Casalis & Louis-Alexandre, 2000; de Jong & Van Der Leij, 2003; Kirby et al., 2003; Singson et al., 2000; Wagner et al., 1997), the amount of variance in reading attributable to phonological skills was found to decrease significantly after the first grade. In the same way, VA span abilities more strongly contributed to regular word and pseudo-word reading performance in first grade than in later grades. Overall, these findings suggest that the VA span, as phoneme awareness, more strongly contributes to the beginning of reading acquisition.

However, cross-grade analysis further revealed a specific link between VA span abilities and performance in irregular word reading. Indeed, whereas the specific influence of VA span on reading performance declines from first to third grade for both the regular words and the pseudo-words, it remains stable across grades for the irregular words. This finding might reflect a specific and long-term involvement of VA span abilities in the acquisition of specific orthographic knowledge.

The overall findings thus suggest that the VA span directly influences the process of reading acquisition. There is a relationship between VA span abilities and reading skills at all grades. The VA span plays an important role in reading performance from the beginning of literacy instruction; its influence on reading performance remains all along primary school. However, a sustained influence of VA span on reading performance was found over grades for the irregular words only, whereas a decreasing role of VA span abilities was observed on regular word and pseudo-word reading performance. A strong issue was further to show that the contribution of VA span to reading performance is independent of phoneme awareness skills. In the following, we will try to interpret these data in light of the multitrace memory model of reading (Ans et al., 1998)

Role of the VA span in pseudo-word reading acquisition

In line with previous findings (e.g., Bradley & Bryant, 1983; Hulme et al., 2002; Laing & Hulme, 1999; Muter et al., 1998; Wimmer, Landerl, Linortner, & Hummer, 1991), our data provide evidence for an association between pseudo-word reading and phoneme awareness in beginning readers. The main contribution of the current study was however to show that a substantial amount of variance in pseudo-word reading was independently accounted for by VA span abilities. Moreover, variance in pseudo-word reading performance uniquely explained by the VA span was larger in first than later grades. These overall findings suggest that, like phoneme awareness, the VA span more strongly contributes to pseudo-word reading performance at the beginning of literacy instruction. Such findings are compatible with the multitrace memory model of reading (Ans et al., 1998) which assumes that one of the key components involved in pseudo-word reading, namely graphemic parsing, is controlled by visual attentional processes (see Facoetti et al., 2006; Facoetti, Lorusso, Cattaneo, Galli, Molteni, & Zorzi, submitted, for a similar claim, and Perry et al., 2007, for a concurrent computational account). In line with the model predictions, converging evidence from experimental and neuroimaging data have been reported supporting the involvement of VA processes in long pseudo-word reading (Valdois et al., 2006).

Within the MTM framework, the larger the VA window, the greater the number of letters which can be simultaneously processed, thus enabling processing of larger-than-letters orthographic units, such as graphemes or syllables (Bosse et al., 2007; Valdois et al., 2004). If the ability to process relevant orthographic units depends on the VA span, then efficiency of VA span abilities might be critical for the acquisition of analytic processing skills, especially for languages with a high number of multiletter graphemes such as French or English. VA span abilities might thus be crucial at the beginning of reading acquisition for the identification of graphemes within written words. VA span and phoneme awareness skills would thus both contribute to the efficient learning of sub-lexical spelling-to-sound mappings.

Role of the VA span in irregular word reading

Our results further show that, in addition to phoneme awareness and at all grades, VA span abilities contribute independently to variance in irregular word reading. Contribution of the VA span to irregular word reading performance was substantial at Grade 1 and remained stable over grades, whereas the influence of phonological skills decreased substantially after Grade 1. These data suggest that VA span abilities might play a role in the long-term establishment of lexical orthographic knowledge.

It is widely accepted that phonological skills and decoding abilities take part in the development of orthographic knowledge (e.g., Cunningham et al., 2002; Ehri, 1998; Share, 1995, 1999; Share, 2004; Sprenger-Charolles et al., 2003; Sprenger-Charolles, Siegel, & Bonnet, 1998). In agreement with this statement, the phonological factor was found to contribute significantly to irregular word reading accuracy in the present study. However, its contribution was rather moderate after Grade 1. It has been already pointed out that phonemic skills (and/or phonological recoding) are necessary but not sufficient to explain irregular word reading performance (Bowers, Golden, Kennedy, & Young, 1994; Griffiths & Snowling, 2002). Even after controlling for decoding skills, the ability to memorise orthographic information substantially differs between readers (e.g., Barker et al., 1992; Di Betta & Romani, 2005; Olson et al., 1990). In French, Sprenger-Charolles et al. (2003) found that orthographic knowledge at Grade 1 predicted irregular word reading accuracy at Grade 4, after having extracted the part of variance explained by decoding skills (see also Cunningham et al., 2002). Most previous studies thus provide converging evidence that orthographic learning does not solely rely on phonological skills. A number of non phonological variables have been put forward as potential sources of orthographic learning. The involvement of some environmental variables such as print exposure (Cunningham & Stanovich, 1993) or other cognitive skills – such as morphological awareness (e.g., Casalis & Louis-Alexandre, 2000; Singson et al., 2000) or rapid automatised naming (e.g., Nikolopoulos, Goulandris, Hulme, & Snowling, 2006; Powell, Stainthorp, Stuart, Garwood, & Quinlan, 2007; Wolf & Bowers, 1999) has been debated. The present paper brings new insights on this issue in suggesting that the VA span, because of its involvement in the extraction of orthographic information from the input string during reading, plays a critical role in the acquisition of word-specific knowledge. The strong relationship found here between VA span and reading speed gives further support to this hypothesis.

Such a privileged relationship is in agreement with the MTM model according to which irregular word reading primarily relies on global processing through the activation of word traces which are created during the reading process each time the entire input orthographic sequence and the entire output phonological sequence of the input item are simultaneously available (Valdois et al., 2004). Therefore, word trace creation requires a VA span large enough for all of the letters of the input string to be simultaneously identified across all positions. It follows that the acquisition of specific orthographic knowledge in memory should in part depend on VA span abilities.

VA span and Rapid automatised naming

A growing body of data from studies of reading disabled children (Compton, Defries, & Olson, 2001; Wolf & Bowers, 1999; Wolf et al., 2002) or normal reading acquisition (Manis, Seidenberg, & Doi, 1999; Schatschneider, Carlson, Francis, Foorman, & Fletcher, 2002; Powell et al., 2007) provides evidence that naming speed (as measured through tests of rapid automatized naming: RAN) and reading ability strongly relate. However, the nature of the cognitive processes underlying rapid automatized naming and their relationship with reading acquisition remains largely debated (Vellutino et al., 2004). At first glance, the RAN tasks and the VA span tasks could appear as rather similar, as they both require the participants to identify and quickly name letters in strings. However, the VA span tasks differ from the RAN tasks on a number of critical features. Because letter strings are made available for only a short time, the VA span tasks require the extraction and storage of visual information in visual short term memory. On the contrary, visual information remains available throughout processing in the RAN task which thus does not require storage in visual short term memory. It follows that the VA span tasks alone specifically assess those visual processes involved in the extraction of multiple information for its subsequent storage in visual short term memory (see Bundesen, 1990; 1998). It is likely that acquisition of orthographic knowledge in long term memory first requires temporary storage of the entire orthographic information in visual short term memory. Accordingly, VA span tasks might more straightforwardly assess those visual processes involved in the memorisation of lexical orthographic knowledge. It is further noteworthy that RAN performance probably reflects not only those visual processes involved in the extraction of visual information but also visual scanning and articulatory abilities not involved in the letter report tasks. Nevertheless, the two tasks obviously share a number of cognitive mechanisms and the RAN tasks are known to rely on some visual processes (Borley & Kruk, 2006; Powell et al., 2007; Stainthorp, Stuart, Powell, Garwood, & Quinlan, 2006) potentially involved in the report tasks we used to assess VA span abilities. Further research is thus needed to better characterise the nature of the relationship between VA span tasks and RAN tasks.

Conclusion

The main and new finding of this study is to show that, independently from phonological processing, the VA span contributes to reading performance all along primary school. Because of its involvement in the identification and parsing of relevant sub lexical orthographic units, the VA span might play a critical role in the acquisition of spelling-to-sound mappings. Furthermore, a VA span large enough to process all the letters of a word simultaneously is further required for the orthographic sequence of the input word to be memorised and consolidated. Accordingly, VA span abilities are likely to contribute to the enrichment of specific orthographic knowledge all along primary school. Future investigations are required to establish whether the relationship between VA span abilities and learning to read is causal. Such a causal hypothesis would need support from two broad types of evidence, namely longitudinal studies and training studies.

References

Aghababian, V., & Nazir, T. A. (2000). Developing normal reading skills : Aspects of the visual processes underlying word recognition. *Journal of Experimental Child Psychology, 76*, 123-150.

Alloway, T. P., Gathercole, S. E., Willis, C., & Adams, A.-M. (2004). A structural analysis of working memory and related cognitive skills in young children. *Journal of Experimental Child Psychology, 87*, 85-106.

Ans, B., Carbonnel, S., & Valdois, S. (1998). A connectionist multi-trace memory model of polysyllabic word reading. *Psychological Review, 105*, 678-723.

Barker, T. A., Torgesen, J. K., & Wagner, R. K. (1992). The role of orthographic processing skills on five different reading tasks. *Reading Research Quarterly*, *27*, 335-345.

Borley, R., & Kruk, R. (2006, July, 6-8). *Visual processing components of rapid naming.* Paper presented at the Thirteenth Annual Meeting of the Society for the Scientific Study of Reading, Vancouver, Canada.

Bosse, M.-L., Tainturier, M.-J., & Valdois, S. (2007). Developmental dyslexia : the Visual Attention Span hypothesis. *Cognition, 104*, 198-230.

Bowers, P. G., Golden, J., Kennedy, A., & Young, A. (1994). Limits upon orthographic knowledge due to processes indexed by naming speed. In V. W. Berninger (Ed.), *The varieties of orthographic knowledge, Vol. I: Theoretical and developmental issues* (pp. 173-218). Dordrecht, the Netherlands: Kluwer Academic Press.

Bowey, J. A. (2005). Predicting individual differences in learning to read. In M. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 155-172). Oxford, UK: Blackwell.

Bowey, J. A., & Muller, D. (2005). Phonological recoding and rapid orthographic learning in third-graders' silent reading: a critical test of the self-teaching hypothesis. *Journal of experimental child psychology, 92*, 203-219.

Bradley, L., & Bryant, P. (1983). Categorizing sounds in learning to read: A causal connection. *Nature*, *301*, 419-421.

Buchholz, J., & Davies, A. A. (2005). Adults with dyslexia demonstrate space-based and object-based covert attention deficits: Shifting attention to the periphery and shifting attention between objects in the left visual field. *Brain & Cognition*, *57*, 30-34.

Bundesen, C. (1990). A theory of visual attention. *Psychological Review, 97*, 523-547.

Bundesen, C. (1998). Visual selective attention: Outlines of a choice model, a race model and a computational theory. *Visual Cognition, 5*, 287-309.

Bundesen, C., Habekost, T., & Kyllingsbaek, S. (2005). A neural theory of visual attention: Bridging cognition and neurophysiology. *Psychological Review, 112*, 291-328.

Casalis, S., & Louis-Alexandre, M. F. (2000). Morphological analysis, phonological analysis and learning to read French: A longitudinal study. *Reading and Writing: An Interdisciplinary Journal, 12*, 303-335.

Castles, A., & Coltheart, M. (1996). Cognitive correlates of developmental surface dyslexia: A single case study. *Cognitive Neuropsychology*, *13*, 25-50.

Castles, A., & Coltheart, M. (2004). Is there a causal link from phonological awareness to success in learning to read? *Cognition*, *91*, 77-111.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review*, *108*, 204-256.

Compton, D. L., Defries, J. C., & Olson, R. K. (2001). Are RAN- and phonological awareness-deficits additive in children with reading disabilities? *Dyslexia, 7*, 125-149.

Cunningham, A. E. (2006). Accounting for children's orthographic learning while reading text: Do children self-teach? *Journal of Experimental Child Psychology*, *95*, 56-77.

Cunningham, A. E., Perry, K. E., Stanovich, K. E., & Share, D. L. (2002). Orthographic learning during reading: Examining the role of the self-teaching. *Journal of Experimental Child Psychology, 82*, 185-199.

Cunningham, A. E., & Stanovich, K. E. (1993). Children's literacy environments and early word recognition skills. *Reading and Writing: An Interdisciplinary Journal*, *5*, 193-204.

de Jong, P. F., & van der Leij, A. (1999). Specific contributions of phonological abilities to early reading acquisition: Results from a dutch latent variable longitudinal study. *Journal of Educational Psychology, 91*, 450-476.

de Jong, P. F., & Van Der Leij, A. (2003). Developmental changes in the manifestation of a phonological deficit in dyslexic children learning to read a regular orthography. *Journal of Educational Psychology, 95*, 22-40.

Deacon, S. H., & Kirby, J. R. (2004). Morphological awareness: Just "more phonological"? The roles of morphological and phonological awareness in reading development. *Applied Psycholinguistics, 25*, 223-238.

Di Betta, A.M., & Romani, C. (2005). Lexical learning and dysgraphia in a group of adults with developmental dyslexia. *Cognitive Neuropsychology*, 22, 1-26.

Dixon, P., & Shedden, J. M. (1993). On the nature of the span of apprehension. *Psychological Research*, *55*, 29-39.

Dubois, M., Lafaye de Micheaux, P., Noël, M. P., & Valdois, S. (2007). Pre-orthographical constraints on visual word recognition: Evidence from a case study of developmental surface dyslexia. *Cognitive Neuropsychology, 24*, 623-660.

Duncan, J., Bundesen, C., Olson, A., Humphreys, G., Ward, R., Kyllingsbaek, S., van Raamsdonk, M., Rorden, C., & Chavda, S. (2003). Attentional functions in dorsal and ventral simultanagnosia. *Cognitive Neuropsychology*, *20*, 675-701.

Ehri, L. (1991). The development of reading and spelling in children: An overview. In M. Snowling & M. Thomson (Eds.), *Dyslexia: integrating theory and practice* (pp. 63-79). London: Whurr.

Ehri, L. C. (1998). Grapheme-phoneme knowledge is essential for learning to read words in English. In J. L. Metsala & L. Ehri (Eds.), *Word recognition in beginning literacy*. Mahwah, NJ: Lawrence Erlbaum Associates.

Ehri, L. C. (2005). Learning to read words: Theory, findings, and issues. *Scientific Studies of Reading, 9*, 167-188.

Ehri, L. C., Nunes, S. R., Willows, D. M., Schuster, B. V., Yaghoub Zadeh, Z., & Shanahan, T. (2001). Phonemic awareness instruction helps children learn to read: Evidence from the National Reading Panel's meta-analysis. *Reading Research Quarterly, 36*, 250-287.

Facoetti, A. (2004). Reading and selective spatial attention: Evidence from behavioural studies in dyslexic children. In F. Columbus (Ed.), *Trends in dyslexia research* (pp. 117-150). NY: Nova science publishers.

Facoetti, A., Lorusso, M. L., Paganoni, P., Cattaneo, C., Galli, R., Umiltà, C., & Mascetti, G. G. (2003). Auditory and visual automatic attention deficits in developmental dyslexia. *Cognitive brain research, 16*, 185-191.

Facoetti, A., Lorusso, M. L., Cattaneo, C., Galli, R., Molteni, M. & Zorzi, M. (submitted). Multi-sensory spatial attention deficits are predictive of reading performance in developmental dyslexia.

Facoetti, A., Zorzi, M., Cestnick, L., Lorusso, M. L., Molteni, M., Paganoni, P., Umiltà, C., & Mascetti, G. G. (2006). The relationship between visuospatial attention and nonword reading in developmental dyslexia. *Cognitive Neuropsychology*, 23, 841-855.

Gayan, J., & Olson, R. K. (2003). Genetic and environmental influences on individual differences in printed word recognition. *Journal of Experimental Child Psychology, 84*, 97-123.

Goswami, U., & Bryant, P. (1990). *Phonological skills and learning to read*. Hove: Lawrence Erlbaum Associates.

Goulandris, N. K., & Snowling, M. (1991). Visual memory deficits: A plausible cause of developmental dyslexia? Evidence from a single case study. *Cognitive Neuropsychology, 8,* 127-154.

Griffiths, Y. M., & Snowling, M. (2002). Predictors of exception word and nonword reading in dyslexic children: The severity hypothesis. *Journal of Educational Psychology*, *94*, 34-43.

Hanley, J. R., & Gard, F. (1995). A dissociation between developmental surface and phonological dyslexia in two undergraduate students. *Neuropsychologia*, *33*, 909-914.

Harm, M. W., & Seidenberg, M. S. (1999). Phonology, reading acquisition, and dyslexia: Insights from connectionist models. *Psychological Review, 106*, 491-528.

Hawelka, S., & Wimmer, H. (2005). Impaired visual processing of multi-element arrays is associated with increased number of eye movements in dyslexic reading. *Vision Research, 45*(7), 855-863.
Howard, D., & Best, W. (1996). Developmental phonological dyslexia: Real word reading can be completely normal. *Cognitive Neuropsychology, 13*, 887-934.
Hulme, C., Hatcher, P. J., Nation, K., Brown, A., Adams, J., & Stuart, G. (2002). Phoneme awareness is a better predictor of early reading skill than onset-rime awareness. *Journal of Experimental Child Psychology, 82*, 2-28.
Jacquier-Roux, M., Valdois, S., & Zorman, M. (2002). *l'Odédys, un outil de dépistage des dyslexies*. Grenoble: Laboratoire cogni-sciences, IUFM de Grenoble.
Kennedy, A., Radach, R., Heller, D., & Pynte, J. (2000). *Reading as a perceptual process*. Amsterdam: Elsevier Science.
Kirby, J. R., Parrila, R. K., & Pfeiffer, S. L. (2003). Naming speed and phonological awareness as predictors of reading development. *Journal of Educational Psychology, 95*, 453-464.
Kwon, M., Legge, G. E., & Dubbels, B. R. (2007). Developmental changes in the visual span for reading. *Vision research, 47*, 2889-2900.
Laberge, D., & Brown, V. (1989). Theory of attentional operations in shape identification. *Psychological Review, 96*, 101-124.
Laberge, D., & Samuels, S. J. (1974). Toward a theory of automatic information processing in reading. *Cognitive Psychology, 3*, 293-323.
Laing, E., & Hulme, C. (1999). Phonological and semantic processes influence beginning readers' ability to learn to read words. *Journal of Experimental Child Psychology, 73*, 183-207.
Lassus-Sangosse, D., N'Guyen-Morel, M. A., & Valdois, S. (2008). Sequential or simultaneous visual processing deficit in developmental dyslexia, *Vision Research*, 48, 979-988.
Lefavrais, P. (1965). *Test de l'Alouette*. Paris: Editions du centre de psychologie appliquée.
Lété, B., Sprenger-Charolles, L., & Colé, P. (2004). MANULEX: A grade-level lexical database from French elementary-school readers. *Behavior Research Methods, Instruments, & Computers, 36*, 156-166.
Lovegrove, W. J., Martin, F., & Slaghuis, W. L. (1986). A theoretical and experimental case for a visual deficit in specific reading disability. *Cognitive Neuropsychology, 3*, 225-267.
Manis, F. R., Seidenberg, M. S., & Doi, L. M. (1999). see dick RAN: Rapid naming and the longitudinal prediction of reading subskills in first and second graders. *Scientific Studies of Reading, 3*, 129-157.
McConkie, G. W., & Rayner, K. (1975). The span of the effective stimulus during a fixation in reading. *Perception and Psychophysics, 17*, 578-586.
Mousty, P., Leybaert, J., Alegria, J., Content, A., & Morais, J. (1994). BELEC: Une batterie d'évaluation du langage écrit et de ses troubles. In J. Gregoire & B. Piérart (Eds.), *Evaluer les troubles de la lecture: Les nouveaux modèles théoriques et leurs implications diagnostiques* (pp. 127-145). Bruxelles: De Boeck.
Muter, V., Hulme, C., Snowling, M., & Taylor, S. (1998). Segmentation, not rhyming, predicts early progress in learning to read. *Journal of Experimental Child Psychology, 71*, 3-27.
Nation, K., Angell, P., & Castles, A. (2007). Orthographic learning via self-teaching in children learning to read English: Effects of exposure, durability, and context. *Journal of experimental child psychology, 96*, 71-84.
Nazir, T. A. (2000). Traces of print along the visual pathway. In A. Kennedy, R. Radach, D. Heller & J. Pynte (Eds.), *Reading as a perceptual process* (pp. 3-22). Amsterdam: Elsevier Science.
Nikolopoulos, D., Goulandris, N., Hulme, C., & Snowling, M. (2006). The cognitive bases of learning to read and spell in Greek: Evidence from a longitudinal study. *Journal of Experimental Child Psychology, 94*, 1-17.
Olson, R., Wise, B., Conners, F., & Rack, J. (1990). Organization, heritability, and remediation of component word recognition and language skills in disabled readers. In T. H. Carr & B. A. Levy (Eds.), *Reading and its development: Component skills approaches* (pp. 261-322). san Diego: Academic Press.
Pammer, K., Lavis, R., Cooper, C., Hansen, P. C., & Cornelissen, P. L. (2005). Symbol-string sensitivity and adult performance in lexical decision. *Brain Lang, 94*(3), 278-296.

Pammer, K., Lavis, R., Hansen, P., & Cornelissen, P. L. (2004). Symbol-string sensitivity and children's reading. *Brain Lang, 89*(3), 601-610.
Pelli, D. G., Burns, C. W., Farell, B., & Moore-Page, D. C. (2006). Feature detection and letter identification. *Vision Research, 46*, 46-74.
Perfetti, C. (1992). The representation problem in reading acquisition. In P. Gough, L. Ehri & R. Treiman (Eds.), *Reading acquisition*. Hillsdale, NJ: Lawrence Erlbaum Associates.
Perry, C., Ziegler, J. C., & Zorzi, M. (2007). Nested incremental modeling in the development of computational theories: The CDP+ model of reading aloud. *Psychological Review, 114*, 273-315.
Powell, D., Stainthorp, R., Stuart, M., Garwood, H., & Quinlan, P. (2007). An experimental comparison between rival theories of rapid automatized naming performance and its relationship to reading. *Journal of Experimental Child Psychology, 98*, 46-68.
Prado, C., Dubois, M., & Valdois, S. (2007). The eye movements of dyslexic children during reading and visual search: Impact of the visual attention span. *Vision Research, 47*, 2521-2530.
Ramus, F., Rosen, S., Dakin, S. C., Day, B. L., Castellote, J. M., White, S., & Frith, U. (2003). Theories of developmental dyslexia: Insights from a multiple case study of dyslexic adults. *Brain, 126*, 841-865.
Raven, J. C., Court, J. H., & Raven, J. (1998). Progressive matrices standard (PM38). Paris: EAP.
Rayner, K. (1986). Eye movements and the perceptual span in beginning and skilled readers. *Journal of Experimental Child Psychology, 41*, 211-236.
Rayner, K. (1998). Eye movements in reading and information processing: 20 years of Research. Psychological Bulletin, 124(3), 372-422.
Rayner, K., Liversedge, S. P., White, S. J., & Vergilino-Perez, D. (2003). Reading disappearing text: cognitive control of eye movements, *Psychological Science 14* , 385–388.
Romani, C., Ward, J., & Olson, A. (1999). Developmental surface dysgraphia: What is the underlying cognitive impairment? *The Quarterly Journal of Experimental Psychology, 52A*, 97-128.
Schatschneider, C., Carlson, C. D., Francis, D. J., Foorman, B. R., & Fletcher, J. M. (2002). Relationship of rapid automatized naming and phonological awareness in early reading development: Implications for the double-deficit hypothesis. *Journal of Learning Disabilities, 35*, 245-256.
Seidenberg, M. S. (1992). Dyslexia in a computational model of word recognition in reading. In P. Gough, L. Ehri & R. Treiman (Eds.), *Reading acquisition* (pp. 243-274). Hillsdale, NJ: Lawrence Erlbaum Associates.
Sénéchal, M., & Kearnan, K. (2007). The role of morphology in reading and spelling. *Advances in Child Development and behavior, 35*, 297-325.
Share, D. L. (1995). Phonological recoding and self-teaching: Sine qua non of reading acquisition. *Cognition, 55*, 151-218.
Share, D. L. (1999). Phonological recoding and orthographic learning: A direct test of the self-teaching hypothesis. *Journal of Experimental Child Psychology, 72*, 95-129.
Share, D. L. (2004). Orthographic learning at a glance: on the time course and developmental onset of self-teaching. *Journal of Experimental Child Psychology, 87*(4), 267-298.
Share, D. L. (2008). On the anglocentricities of current reading research and practice: the peril of overreliance on an "outlier" orthography. *Psychological Bulletin*, 134 (4), 584-615.
Shovman, M., & Ahissar, M. (2006). Isolating the impact of visual perception on dyslexics' reading ability. *Vision Research, 46*, 3514-3425.
Singson, M., Mahony, D., & Mann, V. (2000). The relation between reading ability and morphological skills: Evidence from derivation suffixes. *Reading-and-Writing, 12*, 219-252.
Sprenger-Charolles, L., Siegel, L. S., Béchennec, D., & Serniclaes, W. (2003). Development of phonological and orthographic processing in reading aloud, in silent reading, and in spelling: A four-year longitudinal study. *Journal of Experimental Child Psychology, 84*, 167-263.
Sprenger-Charolles, L., Siegel, L. S., & Bonnet, P. (1998). Reading and spelling acquisition in French: The role of phonological mediation and orthographic factors. *Journal of Experimental Child Psychology, 68*, 134-165.

Stainthorp, R., Stuart, M., Powell, D., Garwood, H., & Quinlan, P. (2006, July, 6-8). *A preliminary report of causal factors underlying performance in rapid automatised naming (RAN) tasks.* Paper presented at the Thirteenth Annual Meeting Society for the Scientific Study of Reading, Vancouver, Canada.
Stanovich, K. E., Cunningham, A. E., & Cramer, B. B. (1984). Assessing phonological awareness in kindergarden children: Issues of task comparability. *Journal of Experimental Child Psychology, 38*, 175-190.
Stein, J. F. (2003). Visual motion sensitivity and reading. *Neuropsychologia*, *41*, 1785-1793.
Valdois, S., Bosse, M.-L., Ans, B., Carbonnel, S., Zorman, M., David, D., & Pellat, J. (2003). Phonological and visual processing deficits can dissociate in developmental dyslexia: Evidence from two case studies. *Reading and Writing: An Interdisciplinary Journal*, *16*, 541-572.
Valdois, S., Bosse, M.-L., & Tainturier, M.-J. (2004). The cognitive deficits responsible for developmental dyslexia: Review of evidence for a selective visual attention disorder. *Dyslexia*, *10*, 1-25.
Valdois, S., Carbonnel, S., Juphard, A., Baciu, M., Ans, B., Peyrin, C., & Segebarth, C. (2006). Polysyllabic pseudo-word processing in reading and lexical decision: Converging evidence from behavioral data, connectionist simulations and functional MRI. *Brain Research, 1085*, 149-162.
Valdois, S. & Lassus-Sangosse, D. (under revision). The visual attention span deficit in developmental dyslexia is visual not verbal: A reply to Hawelka & Wimmer (2008).
Vellutino, F. R. (1979). *Dyslexia: theory and research*. Cambridge, MA: MIT Press.
Vellutino, F. R., Fletcher, J. M., Snowling, M. J., & Scanlon, D. M. (2004). Specific reading disability (dyslexia): What have we learned in the past four decades? *Journal of Child Psychology and Psychiatry, 45*, 2-40.
Wagner, R. K., Torgesen, J. K., Rashotte, C. A., Hecht, S. A., Barker, T., Burgess, S. R., Donahue, J., & Garron, T. (1997). Changing relations between phonological processing abilities and word-level reading as children develop from beginning to skilled readers: A 5-year longitudinal study. *Developmental Psychology, 33*, 468-479.
Wimmer, H., Landerl, K., Linortner, R., & Hummer, P. (1991). The relationship of phonemic awareness to reading acquisition: More consequence than precondition but still important. *Cognition*, *40*, 219-249.
Witton, C., Talcott, J., Hansen, P. C., Richardson, A., Griffiths, T., Rees, A., Stein, J. F., & Green, G. (1998). Sensitivity to dynamic auditory and visual stimuli predicts nonword reading ability in both dyslexic and normal readers. *Current Biology*, *8*, 791-797.
Wolf, M., & Bowers, P. G. (1999). The double-deficit hypothesis for the developmental dyslexias. *Journal of Educational Psychology, 91*, 415-438.
Wolf, M., Goldberg O'Rourke, A., Gidney, C., Lovett, M., Cirino, P., & Morris, R. (2002). The second deficit: An investigation of the independence of phonological and naming-speed deficits in developmental dyslexia. *Reading and Writing: An Interdisciplinary Journal*, *15*, 43-72.
Wolford, G. (1975). Perturbation model for letter identification. *Psychological Review*, *82*, 184-199.
Ziegler, J. C., & Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: a psycholinguistic grain size theory. *Psychol Bull*, *131*(1), 3-29.

APPENDIX

Lists of phoneme awareness items

Phoneme segmentation items:

four; épaule; chauffage; cri; porte; allumer; outil; plage; crapaud; encre; cadeau; régler; jouet; abri; armure.

Acronym items:

photo – artistique; chien – accroupi; bébé – ourson; tortue – enlevée; bel – oiseau; cher – auguste; gant – épais; cousin – infernal; gentil – invité; grave – entorse.

Phoneme deletion items

outil; fontaine; drapeau; courage; ombrage; planète; droit; frite; capitaine; ampoule; dragon; virgule; statue; gravier; hiver; impossible; envoyer; planche; grappe; oubli.

Spoonerism items (third and fifth graders only)

banane – ficelle; fourmi – journal; mouton – tulipe; manège – volcan; jardin – bagage; tomate – camion; verrou – falaise; panier – bureau; baleine – miroir; bougie – poupée.

Table 1

Characteristics of the participants of each grade

	Grade 1	Grade 3	Grade 5
N	157	126	134
	Mean (SD)	Mean (SD)	Mean (SD)
Chronological age (months)	82 (4 months)	107 (5 months)	131 (6 months)
Reading age (months)	84 (8 months)	103 (15 months)	124 (20 months)
Non verbal IQ percentile (Raven)	52.6 (27.5)	46.3 (25.7)	53.5 (27.7)

Table 2

Mean performances in reading (RW = regular words, IW = irregular words, PW = pseudo-words), phoneme awareness, VA span and control tasks (letter identification threshold in milliseconds, memory score as the sum of the two forward and backward digit spans) for each grade

	Grade 1	Grade 3	Grade 5	ANOVAs	
	Mean (SD)	Mean (SD)	Mean (SD)	F (ddls)	MSe
Reading					
RW reading score (percent)	71.5 (25)	89 (11)	95.9 (5)	82.7 (2, 414)***	281
IW reading score (percent)	44 (23)	70.3 (16)	86.7 (10)	215.5 (2, 414)***	314
PW reading score (percent)	57 (26.5)	79.3 (13)	87.2 (10)	105.2 (2, 414)***	343
Reading rate (seconds per word)	4.2 (2.6)	1.4 (0.7)	1.0 (0.3)	54.1 (2, 411)***	1396
Phoneme awareness					
Deletion (percent)	49.3 (31.5)	72.9 (23.5)	80.9 (19.1)	60.5 (2, 414)***	657
Segmentation (percent)	41.3 (31.9)	43.1 (29.7)	53.0 (26.6)	6.3 (2, 414)**	876
Acronyms (percent)	64.6 (30.6)	72.9 (24.7)	81.3 (22.0)	14.5 (2, 414)***	692
Spoonerisms (percent)		58.0 (30.0)	73.3 (28.2)	8.4 (1, 258)**	545
VA span					
Global report: letter-score (percent)	57.0 (14.4)	78.1 (11.5)	84.1 (10.3)	196.2 (2, 414)***	151
Global report: string-score (percent)	7.3 (13.9)	33.5 (24.0)	46.7 (26.3)	126 (2, 414)***	467
Partial report (percent)	66.6 (17.6)	82.1 (11.7)	87.6 (9.0)	93.5 (2, 411)***	185
Control tasks					
Letter identification (weighted accuracy score)	67.6 (33.9)	106.7 (33.3)	123.9 (27.5)	121.6 (2, 412)***	1008
Memory score (forward + backward digit spans)	8.2 (1.2)	9.0 (1.4)	10.0 (1.5)	61.6 (2, 413)***	2

Notes. 1- ** = $p < .01$; *** = $p < .001$

2-Grade 1: N = 157 (except for memory score: 156); Grade 3: N = 126 (except for partial report: 124); Grade 5: N = 134 (except for partial report: 133).

Table 3

Correlation matrix among all the measures computed across grade (N = 417 except for partial report (414) and memory score (416); for acronyms: N = 260). Above the diagonal, partial correlations with age partialed out. Below the diagonal, partial correlations with the effects of age, Raven matrices, memory score and letter identification partialed out. (RW = Regular Word, IW = Irregular Word, PW = Pseudo-Word).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. RW score		**.74**	**.83**	**-.70**	**.48**	**.33**	**.47**	**.53**	**.47**	**.29**	**.37**	**.19**	**.25**	**.34**
2. IW score	**.69**		**.73**	**-.63**	**.47**	**.33**	**.38**	**.52**	**.52**	**.44**	**.36**	**.23**	**.29**	**.30**
3. PW score	**.80**	**.69**		**-.67**	**.47**	**.32**	**.44**	**.55**	**.49**	**.36**	**.39**	**.23**	**.23**	**.30**
4. Reading rate	**-.67**	**-.58**	**-.63**		**-.41**	**-.25**	**-.33**	**-.39**	**-.55**	**-.32**	**-.41**	**-.26**	**-.22**	**-.22**
5. Deletion	**.38**	**.36**	**.36**	**-.31**		**.52**	**.44**	**.38**	**.42**	**.35**	**.30**	**.27**	**.30**	**.37**
6 Segmentation	**.20**	**.20**	**.21**	-.14	**.41**		**.48**	**.40**	**.27**	**.23**	.08	**.18**	**.31**	**.32**
7 Acronym	**.36**	**.25**	**.32**	**-.22**	**.30**	**.37**		**.34**	**.26**	**.16**	**.21**	**.21**	**.30**	**.40**
8 Spoonerism	**.41**	**.39**	**.47**	**-.30**	**.23**	**.23**	.17		**.37**	**.37**	**.21**	**.19**	**.42**	**.37**
9 Global report, Letters	**.38**	**.43**	**.40**	**-.47**	**.27**	.11	.08	**.22**		**.80**	**.60**	**.51**	**.33**	**.26**
10. Global report, String	**.18**	**.35**	**.25**	**-.20**	**.20**	.09	-.01	**.23**	**.73**		**.47**	**.42**	**.32**	**.20**
11 Partial report	**.28**	**.26**	**.29**	**-.32**	**.16**	-.06	.07	.06	**.48**	**.34**		**.38**	**.20**	**.24**
12 letter identification													**.21**	**.20**
13. Memory score														**.26**
14. Raven score														

Note. In bold, significant correlations after a Bonferoni adjustment.

Table 4

Results of the factorial analyses, including phonological and letter report tasks, for each grade

	Grade 1		Grade 3		Grade 5	
	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2
Deletion	.75	.36	.70	.30	.76	.11
Segmentation	.88	.04	.81	.07	.83	-.02
Acronym	.76	.22	.73	-.04	.76	.07
Spoonerism	--	--	.61	.30	.59	.39
Global letters	.31	.81	--	--	--	--
Global strings	--	--	.22	.85	.18	.86
Partial report	.05	.92	-.02	.87	-.05	.89

Table 5

Correlations between the factors extracted from factorial analyses (factor 1 = phonological factor, factor 2 = VA span factor) and the other measures for each grade (RW = regular word, IW = irregular word, PW = pseudo-word)

	Grade 1		Grade 3		Grade 5	
	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2
RW score	**.57***	**.41**	**.33**	**.27**	**.35**	**.45**
IW score	**.52**	**.37**	**.39**	**.40**	.21	**.54***
PW score	**.53**	**.41**	**.34**	**.41**	**.34**	**.43**
Reading rate	**-.42**	**-.48**	**-.29**	**-.42**	-.01	**-.53***
Letter Identification	.22	**.37**	.15	**.57***	.13	**.36***
Memory score	**.27**	.21	**.33**	**.28**	**.49***	**.27**
Raven score	**.46***	**.29**	**.28***	.06	**.42***	.25

Note. In bold, the significant correlations after a Bonferoni adjustment ; * indicates significant differences between the correlation of factor 1 and 2 with each measure in each grade

Table 6 :

Multiple regression analyses conducted separately for each grade, predicting reading accuracy (RW = regular word, IW = irregular word, PW = pseudo-word) and reading rate from control variables (entered at the first step: age, Raven score, short term memory, letter identification), phonological (PH) factor and visual attentional (VA) factor: incremental R^2 for each factor when entered at the final step of the analysis, representing the unique contribution of that factor to reading; Total R^2 of the equation including all the 6 predictors.

	Grade 1			
Predictor at the final step	RW	IW	PW	Reading rate
VA Factor	.147***	.134***	.133***	.189***
or				
PH Factor	.248***	.221***	.199***	.142***
Total R^2	.504***	.431***	.452***	.428***
	Grade 3			
VA Factor	.064**	.146***	.128***	.104***
or				
PH Factor	.041*	.081***	.077***	.032*
Total R^2	.275***	.389***	.320***	.308***
	Grade 5			
VA Factor	.134***	.200***	.134***	.207***
or				
PH Factor	.054**	.023*	.068***	.000
Total R^2	.335***	.336***	.302***	.283***

* = $p < .05$, ** = $p < .01$, *** = $p < .001$